THE EVOLUTION OF THE 2014 'DAMALANCHE' FACET LAYER OF SOUTH-CENTRAL AND SOUTHEAST ALASKA

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ABSTRACT: The 2014 mid to late season snowpack in the Eastern Chugach Range of Alaska presented challenges and learning for the heli-ski operations around Thompson Pass, and in the bigger picture the entire Chugach Range and mountains of SE Alaska. The rain event that triggered the widespread avalanche cycle on January 24 and 25, 2014 was known as the "Damalanche" cycle for the Dam that it created on the Lowe River at the mouth of Keystone Canyon. This event, by itself, was not a serious problem further into the winter, but the saturated snowpack that resulted fostered the growth of near-surface facets (via melt-layer recrystallization or "DW faceting") that grew to the size of 5mm depth hoar grains in 'favored' locations. This layer, dubbed the "Damalanche Facets" went through a fascinating period of building, dormancy, activity, dormancy and reactivation. A similar layer formed in SE Alaska and some of the similarities will be addressed. Through more than two months of direct observation we saw varying degrees of strength, propagation and friction; universally poor structure; and widespread continuity of the weak layer. This paper addresses the formation and evolution of the dam facets, lessons learned for forecasting and guiding, and thoughts for tracking similar layers into the future.

KEYWORDS: near-surface faceting, Alaska, avalanche forecasting, melt-layer recrystallization.

1. INTRODUCTION

Alaska is often referred to as a land of extremes. In an avalanche-forecasting context, Alaska does see similar snow grain growth, avalanche cycles, and weak layer types that are found in many other mountain ranges around the world. However, the frequency of encountering different avalanche conditions and the varied nature of them is truly impressive. The 2013/2014 winter season was a classic case of a season that blended elements of a true continental climate in November and December 2013, pursued by a wet slide cycle triggered by 'biblical' rains (Fitzgerald 2014), and then a trip back into the deep freeze for most of January and February 2014. The resulting snowpack was what forecasters encountered as helicopter skiing season started in the Eastern Chugach Range of South-Central Alaska. A similar snowpack existed down in the Coast Range of SE Alaska. (Fig.1)

The intent of this paper is to follow the evolution of the 'Damalanche Facets ' from the point they were developing, through the time they became active, a short period of dormancy, a longer active avalanche cycle, and on to the point they were removed from the snowpack (in this case as melt water). This evolution reinforced recent research pertaining to avalanche release (cited within the paper) and the conclusions at the close of the paper will help illustrate the lessons learned.

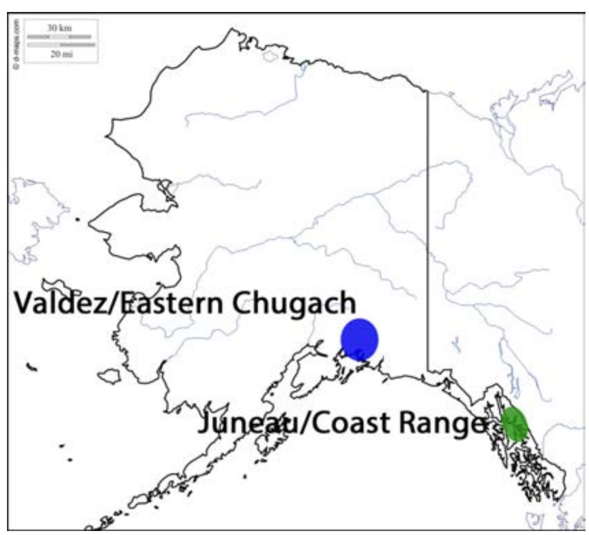

Fig. 1: Map of Study Areas

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2. SEASON HISTORY

The mountains of South Central Alaska (specifically the Chugach Range) are far removed from the mountains of SE Alaska (specifically the Coast Range and Chilkat Range). Despite the 700+ kilometers that lie between the regions, the snowpacks can be quite similar. A review of the season histories that led up to the period of study will show some of the similar events that led to the weak layer formation. Statham et al (2012) track the evolution of weak layers from formation to activity to dormancy to inactivity or extinction. That terminology will be used throughout the narrative that follows.

2.1 *Tough Times on Thompson Pass (Eastern End of the Chugach Range)*

Thompson Pass is known as one of the snowiest places in the world having recorded over 2500 cm of snowfall in a single season. The winter of 2013/2014 did not come close to that total despite a strong start in November. A mid-month storm brought close to a meter of snow, but in the next week no new snow fell, the snowpack shrunk to 30cm, and temperatures dipped as low as -29°C. As expected the snowpack became faceted and depth hoar began developing in some areas. Storms in latter November, mid-December, and around the Winter Solstice weren't enough to keep the snowpack from continued faceting.

A short New Year's storm followed by moderate temperatures through January 11th did little to change the existing snowpack structure of depth hoar and assorted hard wind slabs. Near suicidal skiers in Valdez perked up when snow began to fall on January 13th and a moisture-rich feed started to set up from Hawaii. 75cm fell between January 13-16 bringing the total snow depth to a season high (thus far) of 165cm. On the 17th the Pineapple Express kicked in and snow changed to rain. Turnagain Pass (160 km to the west) caught the brunt of the early part of this Tropical push (Fitzgerald 2014), but the new snow around Thompson Pass rapidly settled as it became rain-soaked. As Turnagain Pass absorbed more and more rain over the 18th and 19th the Eastern end of the Chugach returned to snow with another 33cm falling. What followed on the 21st- 23rd of January will remain in infamy in Valdez for generations.

2.2 *The Damalanche Event – Valdez/Thompson Pass*

Rain began on Thompson Pass on January 21 and continued through the 24th. Recording instruments failed to record accurate rainfall amounts on Thompson Pass, but the Valdez NWS station (40 km away and at sea level) recorded over 279 mm during that period. The results were impressive, to say the least, with avalanches to size D4.5 between Valdez and Thompson Pass and a widespread wet slab avalanche cycle to the north of Thompson Pass that ran on all aspects below 1525m. The huge avalanche that came out of Snowslide Gulch dammed the Lowe River and effectively closed the Richardson Highway (the only road to Valdez) for 12 days. This avalanche led to the name "the damalanche" and all the variations that followed. (Carter and Carter, 2014). On the 24th the Thompson Pass station saw a rain snow mix where a total of 10cm of new snow fell on the rain-saturated snowpack. This is the snow layer that is thought to be what morphed into the Damalanche Facets that is the focus of this paper.

From January 25 to the 27^{th,} the temperatures stayed unseasonably warm, remaining above freezing in the mountains and reached +5°C at Thompson Pass on the 26th. Cooling followed on the 27th of January and there was no new snow until February 12th. That period was marked by generally clear skies, temperatures down to -25°C, generally light winds and very little settlement within the snowpack as the surface snow faceted and the rain-soaked snow gradually froze into a thick crust (knife + hardness).

2.3 *February 2014 on Thompson Pass*

As February progressed a layer of near-surface facets formed over the surface of the rain-soaked snow from late January. The snow that fell following the rains of January 22-24 changed by a near-surface faceting process know as melt-layer recrystallization (Birkeland 1998). The extent to which the upper layer of the snowpack had been saturated by rain would help determine the duration of the faceting. Essentially, until the rain-soaked layer froze into a rain crust it would remain at 0°C and be the heat source for the snow above. Thicker layers of saturated snow could drive the vapor pressure gradient for longer. Thinner layers of snow overlying the saturated snow also increased the temperature gradient. Between these two drivers of melt-layer recrystallization there was an ideal elevation band for facet formation (Jamieson and Langevin, 2004). Too low (<600m) and there was just rain with no storm-ending snow. Too high (>1525m) and the thickness of the new snow inhibited large gradients from forming. After seventeen days the drought ended and from February 13th to the 18th a slab started to build atop the Damalanche Facets leading to the first avalanche cycle on that layer.

Heli-ski operations on Thompson Pass often start with several days to a week of time without a helicopter, allowing time to set-up the base, ski tour, and start a base-line for avalanche forecasting. Forays into the "backyard" starting on February 24th revealed a cranky loud snowpack. Gaining elevation, whumphs increased from localized collapses of a few meters to long running collapses that sent jets of snow up around alders 20 meters away. Cracks were ubiquitous on any slope >20° and previously collapsed snow was collapsing again as we traveled on it. The saving grace for stability was that the slab from the mid-February snows had faceted (this time via diurnal recrystallization) and seemed capable of supporting propagation, but low slab stiffness may have kept the friction high enough at the slab/weak layer interface to prevent avalanche release. Regardless, it was clear that the Damalanche Facets would again be a big problem with subsequent snowfall. Ski tours explored 600-900 meters above the base (elevation 497m), but the arrival of helicopters would soon show the distribution of the Damalanche Facets across the different climatic zones and elevations that are used in daily operations.

2.4 *"Beware the Ides of March"*

The snowpack continued talking to us through the end of February, but on March 2nd the Damalanche Facets got their second load. No new snow fell, but strong northeasterly winds created localized hard slabs 40-100 cm deep along the Thompson Pass Corridor. In mid-elevation cross-loaded terrain the collapses started propagating even further (up to 60 meters) and some of the whumphs became sonic booms. Careful terrain management kept guides and clients out of trouble, but several skier triggered avalanches occurred with a now stiffer slab sitting on top of the Damalanche Facets As operations moved further afield we found that the damalanche facet layer was unusually continuous across all aspects and elevations between 600m and 1525m. That being said there was one zone where the facet layer was the most reactive and that area became a "supermodel" for much of March (i.e. you can look, but don't touch). Small avalanches (R1 to R3, D1 to D2) continued to be remotely and directly triggered by skiers and riders through March 10th, but natural activity seemed to stop by March 4th. On one occasion one of the authors skied up to a flat area that whumpfed loudly. Seconds later a second guide skied past and collapsed the area a second time.

A big storm was forecasted for March 12th and 13th and the hope was that the "crush and flush" might lessen the challenges of the Damalanche Facets.. The storm failed to meet the estimated water amounts, but 40-50cm of mid density snow fell in the Thompson Pass Area. Following three no-fly days, the carnage visible on the 14th was impressive, but not inspiring. Few areas had large-scale natural activity, but there were pockets scattered everywhere between 600 and 1525m averaging 40-70cm in depth. Curiously, despite the natural cycle and ongoing skier triggers, an artillery shoot to protect the Richardson Highway produced virtually no results. Location appeared to be hugely important and it seemed that the typical target points were not the best ones for this slab weak layer combo. Low elevation shots were seemingly the only results from that mission.

Although natural activity seemed to stop by March 14th, human triggered avalanches continued for the next week and a half, including some impressive remote triggering from as far as 400 meters away. By March 25th human triggered avalanches had come to a close, ECT results were mixed with some propagating and some not; and friction was seemingly increasing as more results were resistant planar. The structure remained horrible and an occasional collapse kept the guides wary, but we were starting to guide more complex terrain and feel good about it.

2.5 *April showers…Not so much*

By the start of the April the snow surface was haggard. Various wind events had trashed many slopes. The only saving grace was that diurnal near-surface faceting and surface hoar formation (a layer known as the equinox facets) had improved the skiing in areas that were less wind affected. By April 6th it had been 18 days since the last snowfall, but 10-15cm of fresh snow dressed up the skiing nicely that day.

On April 7th the only avalanche that stepped down to the Damalanche Facets occurred. This incident is discussed in section 4.3 that addresses slab warming effects. The last suspected propagation events from that layer of facets were three separate collapses from three different lower elevation slopes on April 10th. The primary active weak layer for early to mid-April was the shallowly buried Equinox Facets and Surface Hoar. As far as we could tell there were no further avalanches to the Damalanche Facets until the very end April despite above freezing temperatures that arrived after April 17th.

2.6 May – The Shed Cycle cometh

Dormant doesn't mean removed or extinct. Late April/early May marked the start of the shed cycle and the advent of wet slides. On May 4th, the Valdez Avalanche Center noted a wet slab that had likely initiated in the Damalanche Facets and subsequently stepped down to the ground. That avalanche initiated in terrain that was in the heart of the Damalanche Facet terrain (900m and along the Thompson Pass Corridor). There were probably many more avalanches ascribed to this layer as the snowpack continued to go isothermal, but observations became very limited after the heli-operations closed for the season. As one guide stated "You know when I'll trust that layer?… When it's in the river."

2.7 Early Season in Southeast Alaska

The 2013/2014 season in northern portion of Southeast Alaska started out on the dry side in November but picked up substantially in December with well above normal snowfall at sea level. A fairly typical "maritime" December and early January yielded small avalanche cycles. None of this would matter in the end when the reset button was hit Jan 14-16th when a cooler storm was followed by a warm, wet storm that brought 75-100mm of rain up to 4000'. Again very little activity resulted other than small (up to R2D2) slides due to a generally moist and previously rain-tempered snowpack. Some small bouts of light precip followed on the 17-20th with fluctuating temps bringing mixed wet snow and rain into start zones (457m-914m). Record-breaking warm temps ensued on the 22nd-24th (Juneau Airport at sea level) but this time with lighter precipitation. Freezing levels rose to 1828m at the Juneau Icefield weather stations. The rain events in SE Alaska failed to produce a significant full depth cycle as it had in the Chugach, but by months-end the snow surface was remarkably similar; a rain-saturated snowpack with a thickening surface crust. On Jan 29th a small amount of new snow fell at mid elevations. On the 30-31st clear skies allowed radiation cooling despite near freezing air temps and a thin surface crust formed above the wet new snow.

2.8 February 2014 in Southeast

February started dry and cool and faceting in the near-surface layer began in earnest. Temperatures close to, but below freezing coupled with radiation cooling resulted in a strong near-surface gradient. Light to Moderate winds and cool temps continued through Feb 9th when a "Taku" wind event (resulting from an Arctic outbreak) dropped temperatures and the strong wind stripped the developing facets from many exposed locations. As the winds eased and the next storm approached, light dry snow buried the faceting layer. Feb 13-15th then saw an additional 50cm of new snow that started dry and gradually became moist at mid elevations. This thaw (to 762m) was short lived and resulted in a few small direct action slides within storm layers. As temps cooled 30-40cm of dry snow fell on top of the denser snow between Feb 16-18th. On the 17th, hollow cups were widespread between 457m and 914m in Troy Bowl on Douglas Island. Propagation was present but was resistant and compression tests also showed high friction results. In this area, however the slab was only 20-40cm. On the following day, while conducting fieldwork south of Juneau where heavier snowfall dominates, things got interesting. Areas previously stripped by outflow winds showed no signs of faceting above the January crust. But after landing on a ridge at Arthur Peak (~40km SE of Juneau) the 2nd person exiting the helicopter triggered a collapse cracked the whole ridge and riddled the lower start zone with cracks releasing two separate R2/D2 slabs. Later that day while descending Mt Jumbo on Douglas Island, a ski cut resulted in a similar R2/D2 release. On the 22nd, a crew from Alaska Powder Descents experienced nearly a dozen remote triggers on the backside of Mt. McGinnis on the mainland. The day started when the helicopter remotely triggered a R2/D2 slide while landing on the ridge. Subsequent testing showed ECTP SC's. The last part of February saw a warm dry spell last until March 7th. Warm temps and clear weather led to people skiing as if they had nothing to lose. Testing during this period backed up the lack of artificially triggered slides; ECT's and PST's in areas that showed propagation in February now showed low propagation potential (ECTN's) and long critical cut lengths.

2.9 March in Southeast; Dormancy to Rebirth

After a week of warm, dry weather, March saw 12 days of consecutive precipitation adding 80-120cm of new snow. Fluctuating warm temps kept the snowpack settling and the slab stiffening. Tests on Mar 18 & 21 showed impressive propagation including two 3m long ECTP26Q1 and a PST24/277End. The slab now ranged from 1-2m thick, yet was ~100-200 kg/m³ denser than Feb slab densities. After several more days of dry cool weather, one of the more impressive slides was remotely triggered by a party of two on Mt Stewart on Douglas Island. This trigger came after at least 8 people had skied one of the lines across the shallowest part of the slope near rocks. The slide was triggered from a relatively flat and treed area 170m from the nearest slide and 400m away from a second slide (Fig. 2). A crown profile the next day documented a dense slab (168-400 kg/m³) ranging from 1-2m thick overlaying rounding mid-pack depth hoar (from melt layer recrystallization). Late March and April turned out to be drier than normal and the faceted layer slowly healed but was still visually identifiable. Storms that affected the region were generally benign and only led to further settlement and rounding of the weak layer. ECT and PST test results backed up this change by trending toward low propagation potential results. Needless to say, with the March 24th slide visible from the Eaglecrest Ski Area chairlifts, skiers were more gun shy than typical.

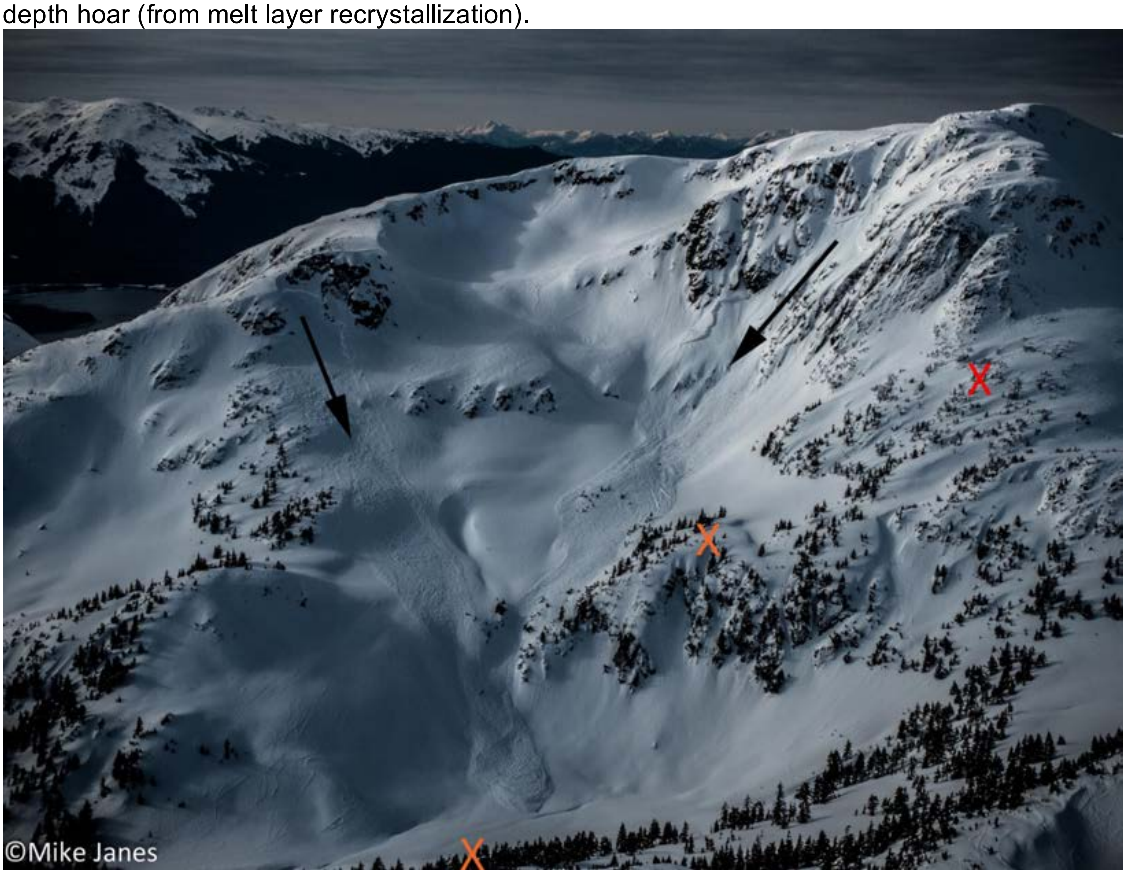

Fig. 2: March 24, 2014 Mt. Stewart Avalanche. The red X (upper right) shows the trigger point and location of other party members (orange X's) as well as the two remotely triggered slides (SS-ASr-R3/D3.5-O) indicated by the black arrows.

3. DEPTH HOAR ON THE SURFACE?!

On occasion, surface and near-surface temperature gradients conspire to create large faceted grains near the surface regardless of the overall depth of the snowpack. In the case of the Thompson Pass Region the Damalanche Facets formed 70 to 150 cm above the ground. Depth hoar seems a misnomer for the larger grains, but that is how they are classified using our existing system. The following sub-sections are a discussion of the grain sizes and types encountered using IACS classifications. (Fierz et al, 2009)

3.1 Grains in the Eastern Chugach

Near-surface faceting is a common process in many ranges, but the resulting facets are generally smaller than 3mm (Birkeland 1998). The Damalanche Facets that formed on the surface of the snowpack from late January to mid-February varied in size by elevation and by distance from the coast. The largest that we encountered were up to 5mm in size and were full-blown depth hoar crystals and varied from cups DHcp ∧ to chains of small depth hoar or large facets DHch ⩓ (up to 3cm in length). At the higher end of where the

Damalanche Facets existed the grains were more commonly 2-3 mm striated facets FCso □ and FCsf ⊠ (Fig. 3). As temperatures warmed and the Damalanche Facets were buried more deeply, grain sizes changed little, but the layer started to round, so that grain types became rounded facets FCxr ⊟ and rounding Depth Hoar DHxr ^.

Fig. 3: 1mm grid. An example (FCso) of one of the many shapes of the Damalanche Facets . Photo by Wendy Wagner

3.2 Grains: Formation in SE Alaska

The grains observed in Southeast Alaska were remarkably similar in both shape and size to those observed in the Chugach. Initial size observations in mid-February were in the 2-4mm range. By early March the size grew to be 3-6mm. In addition, between 457m and 914m the layer was almost always ~2cm thick overlaid by a 3-5mm crust. The most common shape was generally depth hoar cups (DHcp), but regular faceted crystals (FCso) and striated facets were also abundant. While the layer was not present below 457m, it was consistent to 914m. Above 914m it was present as well but was generally a thicker layer with smaller faceted grains and less cupped depth hoar. As loading in late March progressed, the crystals began to round but were still readily identifiable as cupped forms.

4. LESSONS LEARNED AND RE-LEARNED

Unfortunately, we didn't walk away with tremendous new insights into avalanche release, BUT we did gain great experience echoing recent research into avalanche release, propagation, friction, and the influence of warming on propagation.

4.1 Guiding Stategies

Running a heli-ski operation is daunting enough when the stability is good. Looking at the hand that was dealt in late February, we had to figure out where we could go safely as folding was not an option. Fortunately, the owner committed the time and money to do extensive reconnaissance at the start of the season. Most runs were opened and dug on by a team of guides; and soon enough information was gathered to start establishing some trends. As rain-soaked snow was the driving mechanism for the damalanche facet formation, the expectation was that the facets would be less prevalent at our upper elevations (1525m-2400m) where less rain, and more snow, had fallen during latter January at the end of the damalanche event. This proved to be the case and operating at upper elevations became the foundation of our guiding strategy.

Knowing that the largest, and most reactive facets were found between 600m and 1525m, particularly in the circuits closest to our base of operations – we needed to have a way to descend from our upper start zones. We looked closely for our lowest angle terrain with clean run-outs. Terrain traps and large convex start zones were avoided for weeks – even though some of those areas provide our most profitable skiing and often our only skiing when the clouds obscure visibility. Using "defendable" terrain worked well for the operation, but it took time to construct appropriate run-lists in the morning and to achieve buy-in from the guides.

4.2 Avalanche Forecasting AND Communication

Communicating to a group of guides has often been likened to herding cats. Taking cues from teaching avalanche courses, using 21st century technology, and frequently asking "does this make sense?" were key to communicating the message to the guides at the morning meeting. Videos of pit results, pictures of avalanches (regardless of whether they were natural or human triggered), and plotted pits all helped to illustrate current conditions. Guides who hadn't been in the same areas the previous day could see the nature of the activity, or inactivity, and that led to a better understanding of the distribution, sensitivity, and consequences of the avalanches-du-jour. Plotting the problems on the Probability vs. Consequences graph also helped with run selection prior to firing up the helicopters. (Statham et al, 2010) (Sharaf, 2014)

4.3 Slab warming

The mid-March avalanche cycle showed how reactive the damalanche facet layer could be, but avalanche sizes in the Eastern Chugach were consistently size D2 or smaller. Propagation seemed to self-limit by slab depth and hardness, so that portions of slopes would avalanche, but rarely would involve the entire start zone (typically R3 or less). Following the active cycle of March 12-14 the weak layer went dormant for a large part of the heli-ski season. The game changed on April 7th, when air temperatures at lower elevations rapidly rose above the freezing mark and abundant sunshine characterized the day. In technical terms a non-propagating, dormant, conditionally-unstable snowpack progressed to an active propagating snowpack with only the addition of heat (Simenhois and Birkeland, 2008). In non-tech talk a client triggered a much larger avalanche than had been seen in the past two weeks. Skiing at lower elevations in the heat of the day resulted in a soft slab which wrapped a ridge feature in its entirety (R4) and deposited an impressive debris pile (D2.5). (Fig. 4) A client was caught, but deployed his airbag for a happy outcome. This was the most dramatic involvement for the operation for the season and shows the importance of being wary of warming effects on slabs.

4.4 Structure

On a number of different levels it was fascinating to see the change of the grains over a two month period. As mentioned in section 3.1 and 3.2 the grains varied in size. Conditions were ideal for forming large grains; as one person noted conditions were perfect for prolonged faceting – a long period with a large temperature gradient and a long-lasting heat source in relatively high porosity snow. With those conditions large facets and depth hoar could grow anywhere in the snowpack, even at its surface.

As the snowpack warmed and the Damalanche Facets became buried more deeply they slowly began to round. They rarely decreased significantly in size however, and were easy to discern in pits as a thick layer (5-15 cm thick) of significantly larger crystals than the diurnal near-surface facets and wind slabs that overlay them. Avalanching and propagation appeared to correlate more directly to slab properties (stiffness and depth) than structural changes of the weak layer.

As the Chugach snowpack warmed further into late April, and early May, middle and lower elevations (lower than 1066m) became isothermal and the entire snowpack morphed to wet grains of varying sizes. This allowed avalanches to initiate as wet loose slides or wet slabs within the Damalanche Facets and then step down to the ground – through what was previously impenetrable knife-hard rain crust. Until the snowpack became isothermal, the layer of Damalanche Facets could be classified as having four to five structural "lemons" or structural properties conducive to fracture propagation. (McCammon and Schweizer, 2002)

Fig. 4: Photo of the April 7th avalanche where warming seemed to play a pivotal role in accentuating propagation within the Damalanche Facets. The crown was 30-60cm deep, the avalanche ran 350 meters and was classified SS-ASu-R4-D2.5-O

4.5 Strength

Strength as viewed by ECT scores was rarely very low. As slabs were building over the Damalanche Facets scores were consistently moderate (ECT 11-20). ECT results remained in that range well into the dormant period of the facets. Eventually scores moved into the hard range (ECT 21-30), but better indicators of avalanche release were friction observations (fracture character) and whether the crack propagated across the block, or not.

4.6 Continuity

One factor important in avalanche forecasting is the continuity of both the weak layer and the slab. High spatial variability of either can limit propagation and avalanche size. The more continuous the distribution of both the weak layer and the slab, the greater the potential avalanche size. In the

Eastern Chugach the Damalanche Facets exhibited exceptionally good continuity covering all aspects at lower and mid elevations. This distribution provided very few places to hide, or guide. It was fortunate that the March and April storms were few and far between, so slab continuity and depth were less than what was needed for large avalanches (>D3) to occur. Wind events also played into spatial variability of the slabs, as they thinned some areas and deposited in others. The winds also created much stiffer areas of slab and propagation may have self-limited at the slab margins where it became softer.

4.7 Friction

Friction seemed to be slope angle and slab stiffness dependent. Again this seemed to support recent research (Simenhois et al, 2014). Friction is a calculated value, but our surrogates were observations of fracture character and which slope angles would crack, but not release. During the times that the Damalanche Facets became active avalanches rarely started on slopes <35°. Propagation would occur on slopes as gentle as 20° as shown by the abundant cracks in lower angle terrain.

5. CONCLUSION

Avalanche forecasting for such a widespread and sensitive persistent weak layer was one of the best challenges the authors have encountered. The layer demanded respect and constant observation in order to work safely around it. Recent research into fracture propagation, friction, and avalanche release were very helpful in forming theories of what was coming next. The authors are excited for the research to be presented at the 2014 ISSW relating to avalanche release. Avalanche forecasting is a challenging, and humbling, profession that can only improve with fastidious record keeping, abundant field observations, an eye to the science behind it, and a passion for sliding on snow.

ACKNOWLEDGEMENTS

Thanks to Don's co-workers at Valdez Heli-Ski Guides; their observations and critique made for far better avalanche forecasts. We would like to thank Peter Carter for his records from the DOT station on Thompson Pass, Alaska. Also thanks to John Fitzgerald and Doug Krause for their insights into the dam facets as we all tried to figure out what they were going to do. Thank you to Andy Lapkass for several thought-provoking classes and conversations addressing facets, forecasting, and weak layer evolution.

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